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In the Matter of

Spectrum Policy Task Force Seeks Public Comment
on Issues Related to Commission's Spectrum Policies

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Comments by Timothy J. Shepard, Ph.D.

Imagine that 100,000 people go to a football stadium.

Now what if you set aside your experience, and just think like a traditional communication system engineer or spectrum regulator? The acoustic spectrum used for speech communication is a narrow band---just a few kHz wide. You might think we would need to regulate speaking.

"If everybody talked at once, nobody would be able to converse with anyone." But you know otherwise. Anyone can have a conversation with their neighbor even if everyone else is cheering the team on the field.

"OK, maybe everyone can converse with their neighbor, but what about the important public address system. If we let everybody speak however they want, it might make it impossible to engineer an effective public address system." But you know otherwise. Even if we let everybody talk, you can still engineer an effective public address system. And everybody can still converse with their neighbor.

The acoustic case and the electro-magnetic case are more similar than you might realize. In both cases, signal power falls off as the inverse square of the distance. And in any communication system like this, Shannon's capacity theorem determines how much communication can be received by any single receiver as a function of the signal to noise level (the noise being those signals at the receiver which you do not model and somehow compensate for).

We can use our intuition about this football-stadium acoustic situation to help us understand some of the possibilites for the design and regulation of radio systems.

What are the differences?

In the familiar acoustic case (with humans), the receiver design is fixed (our ears and brain).
In the electro-magnetic case: designers have many options for the receiver.

Acoustic: The transmitter design is fixed.
E-M: There are many options for the transmitter.
(Of course the transmitter and receiver will need to be designed together for any particular pairwise communication.)

Acoustic: Language and protocol are what they are.
E-M: There are many option for protocols and signal design.

Acoustic: Spectrum is just a few kHz wide.
E-M: Spectrum is just a few 10's of GHz wide (ten million times more).

Every difference that I can think of between the acoustic and the electromagnetic cases would argue that the electromagnetic case needs less regulation than acoustic.

What regulation might be needed? Football stadiums do often prohibit electronically-amplified megaphones. I'm not sure that any similar prohibition is needed in the E-M case.

Changing Technology Changes the Problem

Imagine we were to give 50,000 different competent radio system engineers the following task:

> Design a pair of walkie talkies so that two people will be able to talk to each other while sitting in two (arbitrary, non-adjacent) seats at the football stadium. There will be 49,999 other engineers doing the same thing you are, and all of their solutions will also be in use. You are allowed no communication with the other 49,999 engineers. (You are encouraged to imagine what they might do.) There are no regulatory constraints. Make your solution robust so that you are sure that it will work.

50 or more years ago, very few, or perhaps none would succeed. 25 years ago, some would succeed. Today most would succeed, perhaps all of them. In the very near future, I expect all would succeed easily. And as Moore's Law marches on, the cost of a successful solution is dropping rapidly.

Cooperation

Above I neglected perhaps the most important difference between the human-acoustic case above and the E-M case. With electronic gadgets we could, in a cooperative design, use store-and-forward relaying to dramatically increase the apparent capacity for the cooperating nodes. (Humans are notoriously unreliable at relaying messages more than a couple of hops.)

This would not require complete cooperation. If we assigned to each of 50 competent radio system engineers the job of designing a system of 2,000 nodes which will be randomly distributed about the football stadium among a total of 100,000 nodes, and each system of 2,000 nodes cooperated internally (but was similarly incognizant of the other 49 systems).

Such federations will naturally form (if not somehow prohibited) because of the value that they would bring to their members.

Efficiency

There is a common notion of spectral efficiency defined as the number of bits per second achieved divided by the bandwidth occupied. This notion of efficiency is wrong. Asking a radio system designer to optimize for this notion of efficiency forces the designer into the bandwidth-limited regime where further increases in bitrate require corresponding exponential increases in signal to noise ratio delivered to the receiver. This tends to maximizes the amount of electro-magnetic pollution produced. Better measures of efficiency would be:

(1) the number of bits communicated per unit of radiated energy,
(2) or the fraction of the transmitted energy that was captured by the receiver, or
(3) the product of (1) and (2)

These measures of efficiency avoid forcing the system designer into a pollution-maximizing corner.

Summary

There seems to be little need for regulation of electromagnetic emissions in the future. Even if there was no regulation (other than perhaps the prohibition of malicious jamming), it would still be possible to design robust and dependable communication (or navigation, or radar) systems. The problem is that regulations that confine the designer to some band tend to rule out the sorts of system designs that could provide robustness. Yet the legacy systems that are deployed today depend upon regulations for their robustness. The path into the future will be tricky.

I suggest that as much as possible, wide-band systems be allowed, at reasonably high power levels, in as many different bands as possible. Current spectrum users should be put on notice that future overlays (or underlays) are likely, and that they should design and operate their systems to be as robust as possible to future wide-band interference. Future proposed systems should be evaluated (in-part) on their robustness in the face of interference from non-cooperating co-channel emitters.

Over the next 20 years or so, the spectrum over 30 MHz (which does not propagate significantly over the horizon) should be systematically deregulated.

Respectfully Submitted,

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